I. DUTTON

MANUAL FOR THE ASSESSMENT, LOCATION AND DESIGN OF REEFWALKING ACTIVITIES

by A.M.Kay and M.J.Liddle

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SCHOOL OF AUSTRALIAN
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GRIFFITH UNIVERSITY

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CONTENTS

1.0 INTRODUCTION

This manual has been divided into three parts each with its own related objectives. Firstly, we present a description of reef walking as a recreational activity which will enable the reader to understand its social significance, and how it is done. Secondly, we have provided basic information on the effect of trampling on corals which will allow the reader to appreciate the environmental impact that reef walking can have. Thirdly, we deal with the methodology of reef walking management. These sections describe the survey techniques used to evaluate a site for reef walking activities, guidleines for management objectives, the management procedures which can be employed to minimise and eliminate reef flat degradation, and methods used to monitor reef walking impact.

2.0 REEF WALKING AS A RECREATIONAL ACTIVITY

2.1 Where and how is reef walking undertaken?

Reef walking is offered as a holiday activity at most of the island tourist resorts along the Great Barrier Reef and it is listed on the itinery of numerous cruise and tour operations based on the north east Queensland coast (Figure 1). It is carried out on the intertidal flats of coral reefs at low tide without the necessity of special physical skills or equipment. If the reef supports a cay with accommodation facilities access to the flats is usually gained by walking from the resort, otherwise small boats are used to ferry people to the reef edge from larger cruise vessels, aircraft or other islands.

There are three main groups of people who reef walk, tourists, university and school students, and scientists.

Tourists and students frequently undertake reef walking in groups of ten and up to thirty or more under the guidance of a tour operator or teacher. These groups usually follow a predetermined route in a fairly loose formation which periodically condenses to focal points when the guide finds something of particular interest. Walking is done on a ragged front rather than in single file and people often meander in and out of the group at will. Both these types of visitor also venture out singly or in small unguided groups and wander freely over the different reef zones. Minor accidents such as stepping through delicate live corals and thin reef surfaces ("pie-crust") are common due to the visitors unfamiliarity with the terrain and environment. Walking sticks are often used as an extra support. Most people walk on sand or smooth solid coral pavement where possible. Areas of fragile and luxurious coral growth are generally avoided unless they are interdigitated by sand pools or sturdy pavement. Only a small part of most reef flats dry during low tide and reef walking usually includes wading in water from ankle to knee deep.

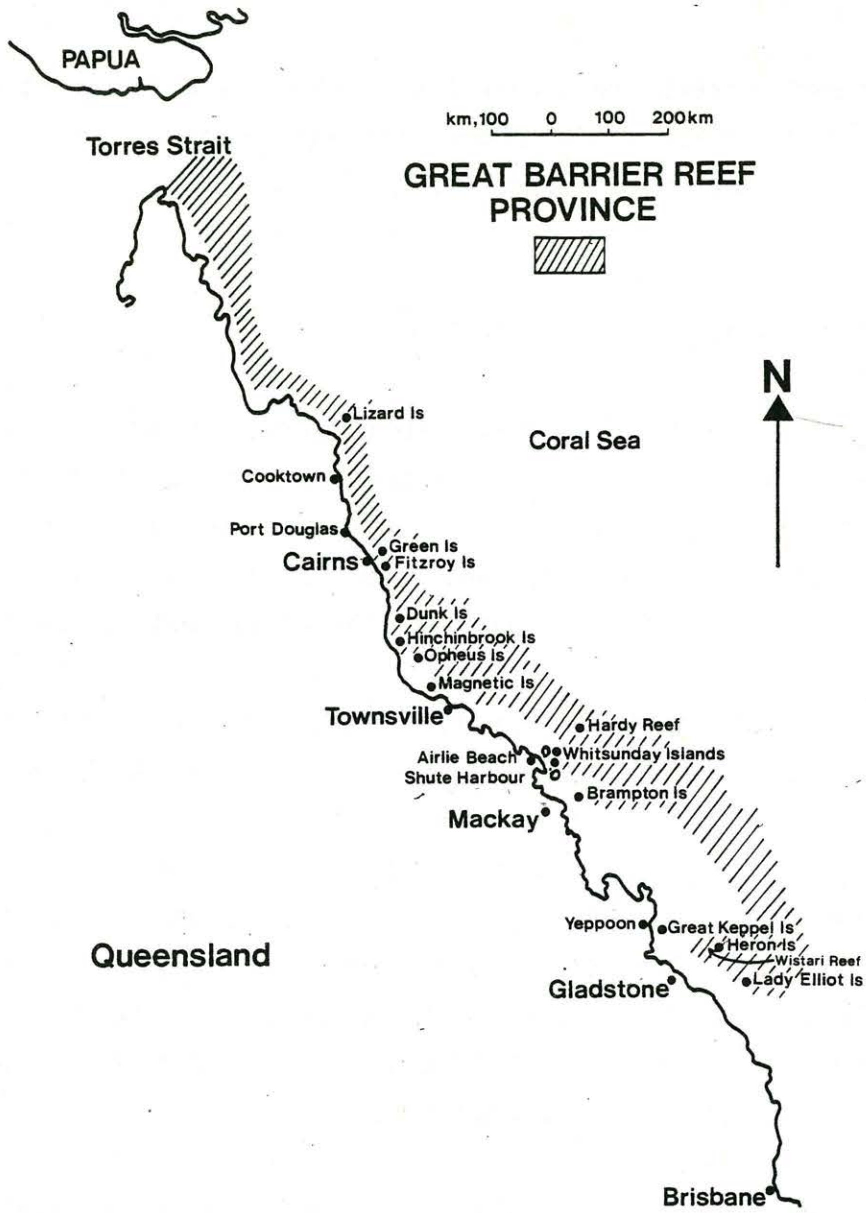


Figure 1 The Great Barrier Reef and major tourist centres

Research workers cross reef flats along the most direct and accessible routes to their field sites with little deviation from day to day. Usually they move about in small groups of two to five or by themselves.

2.2 What motivates people to reef walk?

The vast majority of reef walkers are tourists who are visiting a coral reef as a holiday activity. Most of the remainder are university or school students who are reef walking for educational purposes. Scientists, who are in the minority, are primarily concerned with field research in the coral reef community.

Each group is motivated by a characteristic set of objectives, however, any one individual can belong to more than one group.

For the tourist or holiday maker reef walking is a recreational activity voluntarily undertaken for pleasure and satisfaction. Interaction with the environment in terms of appreciating the aesthetic beauty of the coral community and its inhabitants is most important. The idea of "communing with nature" in an unusual and exotic setting is a big draw card.

For the student reef walking has an educational objective with an emphasis on learning about the biology or geology of the environment and for practising and learning methods for field experimentation and survey.

The scientist main objective is travelling to and from research sites and moving about within them.

2.3 What do people want to see?

When tourists walk on a reef flat they usually have two general expectations about what they wish to see and experience.

Firstly, they hope to see a variety of exotic features that are associated with, and characterize, the coral reef environment. Some favourite items are brightly coloured seastars and fish, big molluscs and hermit crabs and architecturally ornate and delicate corals. Bright colours especially are sought out and the duller coloured corals are often regarded as not being "value for money".

Secondly, most wish to feel that they are experiencing a natural and unspoilt environment. Any obvious signs of environmental degradation interfere with the aesthetic naturalness of the habitat and produce feelings of irritation or disappointment akin to the reaction any customer has upon discovering their new purchase is damaged and they can't return it.

What a student wishes to see on a reef walk will be highly influenced by the educational purpose of the visit. However it can be said with certainty that a largely undisturbed natural environment would be desirable except in those circumstances where the subject of interest is man's impact on the environment.

Since the scientists purpose for reef walking is to undertake field research the question, what do they want to see? does not seem pertinent. Nevertheless it is worthwhile noting that the majority of research concerns natural processes which are optimumly carried out in undisturbed habitats.

3.0 THE ENVIRONMENTAL IMPACT OF REEF WALKING

Three studies have been made of the environmental impact of reef walking. One was undertaken by Woodland and Hooper (1977) on Wistari Reef and the other two by Kay and Liddle (1984a and b) on Heron Island Reef and Hardy Reef respectively (Figure 1). the first two studies were experimental and clearly demonstrated that trampling on reef flat corals can cause considerable damage. The third study was observational and dealt with the use patterns and damage associated with reef walking on a popular reef used for a variety of tourist activities.

3.1 Woodland and Hooper (1977)

The Wistari Reef work (Woodland and Hooper 1977) involved one short term trampling experiment which demonstrated that four people reduced the live coral cover on an area of reef flat 4 metres by 25 metres from 41% to 8% after walking back and forth along it 18 times. An average of 12 kg m^{-2} of live coral was broken off, but most of the robust massive coral colonies, Acanthastrea and Goniastrea, survived.

3.2 Kay and Liddle (1984a)

The Heron Island investigation consisted of several different experiments involving both long and short term trampling trials, growth and survival experiments with damaged coral colonies and fragments, and laboratory tests of branch strength.

The major findings of the trampling trials concerned the susceptibility of different types of coral communities to reef walking damage. There is considerable variation in the composition of the biotic communities and physical surfaces found on reef flats. They range from a partial or complete cover of flattened and encrusting coral colonies on a solid pavement of dead coral to a highly intricate mixture of taller three dimensional coral colonies; solid and honeycombed remains of dead coral colonies, and sand pools. Figure 2 shows photographs of such situations. Zones which are exposed to wave action and water turbulence such as those on edges of reefs, typically have the low compact coral communities while those in more sheltered situations further within the reef platform have the more upright complex coral communities.

Trampling caused much more extensive damage in a sheltered site on the outer reef flat at Heron Island than it did on an exposed reef edge site. The low compact forms of coral on the reef crest were relatively resistant to mechanical disturbances and trampling had little effect on the hard level surface. The percentage cover of corals was not reduced along pathways through this site which were regularly traversed 80 times every three months (equivalent to six or seven times a week) for a year and one half. In comparison trampling broke up many of the upright branching corals and most of the honeycombed dead coral skeletons at the sheltered site. Ditches partially filled with dead coral rubble were formed along pathways which were traversed as infrequently as five times every three months (equivalent to once every two to two and a half weeks) for a year and a half. Also short term trampling trials demonstrated that an average of only 0.7 kg m^{-2} of coral was broken off along 5 metre by 25 cm pathways on the reef crest after 20 traverses whereas eight times as much, 5.7 kg m^{-2}, was broken off on the reef flat site under similar circumstances.

The growth and survival of detached fragments was found to differ between three species of branching corals, Acropora millepora, Acropora palifera, and Pocillopora damicornis (Figure 3) commonly seen on reef flats however one consistent feature emerged, the larger the coral fragment the greater its chances of survival. The experiments with damaged attached colonies of the same species indicated that their chances of survival were high, however, their subsequent growth rates were different. The growth rate of Acropora millepora was not altered by the damage treatments, however the growth rate of both Pocillopora damicornis and Acropora palifera decreased. Another experiment with Porites lutea (Figure 3) demonstrated that trampling can damage corals with massive skeletons even though the skeleton

Figure 2 Examples of different types of coral communities seen on coral reefs.

(a) Flattened coral colonies with very little vertical growth on a solid pavement of dead coral.

(b) Compact coral colonies with some vertical growth on a partially consolidated base of dead coral skeletons.

(c) A mixture of live corals with marked vertical growth, dead coral skeletons and sandy pools.

A

B

C

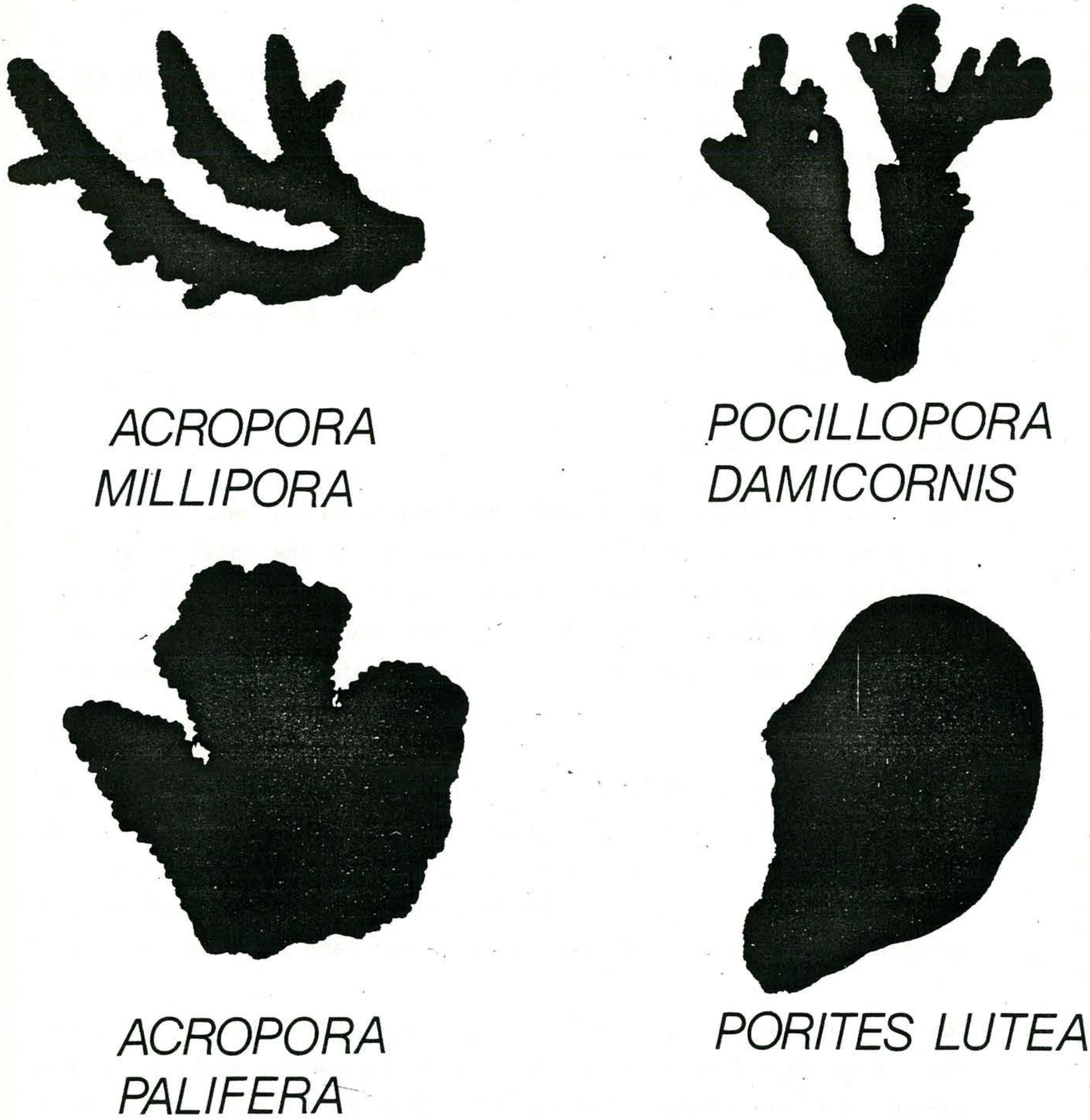


Figure 3 The four species of coral used in Kay and Liddles (1984a) growth and survival experiments.

itself is not mechanically broken up. Temporary and possibly permanent tissue destruction will result when the surface of such corals are repeatedly trodden on. However the results indicated that the damage will be localized to the impact area.

Laboratory tests also showed that the resistance of A. palifera branches to breakage was greater than that of A. millepora and P. damicoruis.

3.3 Kay and Liddle (1984b)

The study at Hardy Reef showed that approximately one tenth of a square kilometre of reef flat, less than 1% of the total intertidal reef flat, was used for reef walking (Figure 4). Between 30,000 and 40,000 reef walkers from the mainland and nearby islands were estimated to visit the area in amphibious aircraft and boats each year.

Surveys showed that the coral communities in this area were mostly low and compact on a consolidated pavement of dead coral similar to the reef crest site at Heron Island which was relatively resistant to trampling damage. One site within this area was characterised by more upright and delicate coral colonies and large sand pools and channels.

There was no obvious sign of trampling damage in the area except along the lagoon edge (Figure 4) of the latter site where small boats ran aground and reef walkers disembarked. This area contained increased amounts of fragmented live and dead coral due to the mechanical impact of boats grounding on the reef edge and the higher concentration, and outward movements, of reef walkers at disembarkation points. The damage was very localized and represented only a tiny fraction of the total reef walking area.

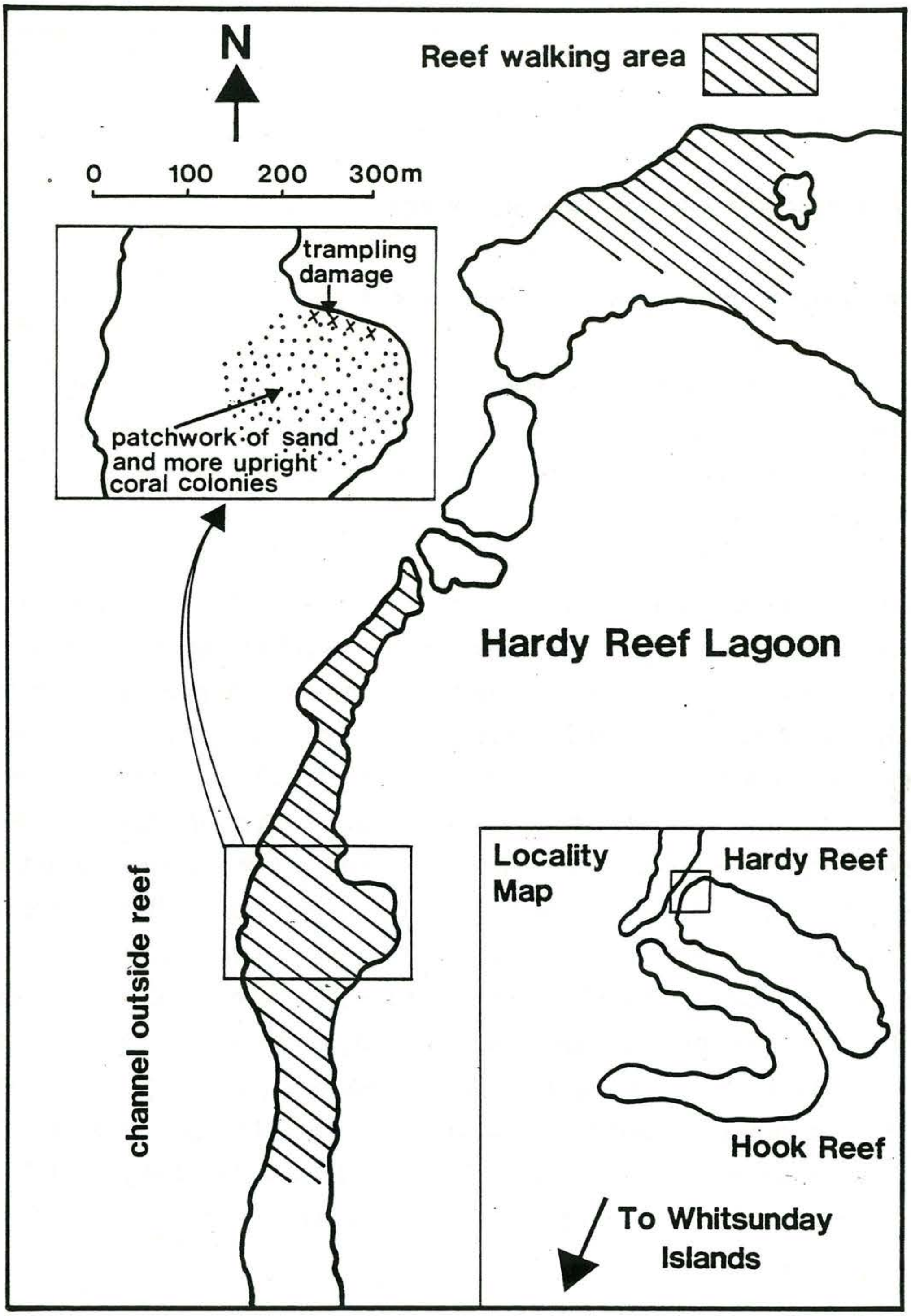


Figure 4 The reef walking area at Hardy Reef.

4.0 THE MANAGEMENT OF REEF WALKING IMPACT

4.1 The purposes of reef walking management

Why must reef walking be managed? The Great Barrier Reef is a vast natural structure most of which remains submerged during tidal fluctuations and human trampling could not pose a serious threat to its survival.

However, as the experimental work reported in this manual shows human trampling can degrade and destroy the structure of localized areas of reef flat. If a particular reef flat becomes a popular site for reef walking it may, in time, loose its natural and unspoilt character so that the aesthetic and recreational needs and desires of the people who visit it are no longer fulfilled. This provides a very good reason for reef walking management, namely to preserve the naturalness and character of an accessible, well known reef walking site for the enjoyment and satisfaction of present and future visitors. It also points to two further reasons. Firstly, the good maintenance and upkeep of an established reef walking site would be a better bet economically for tourist operators than bad publicity over a degraded site and repeated moves to new pristine reef flats. Secondly, no reef is exactly the same as any other and each well managed reef walking site means that a unique habitat is being preserved rather than destroyed.

4.2 The management process

The management of reef walking can be divided into four sequential stages.

These are:

1. Resource evaluation
2. Definition of management objectives
3. Implementation of objectives
4. Monitoring the resource

1. Resource evaluation
   This involves the identification and assessment of those features of the reef flat habitat which are significant to reef walking.

2. Definition of management objectives
   Firstly this involves determining what environmental changes are acceptible at the site without destroying its value as a recreational or educational resource and its ecological integrity. Secondly, it may also involve setting objectives for the interpretive services which will be offered at the site.

3. Implementation of objectives
   The appropriate management and interpretive techniques are chosen to implement the management objectives in the field.

4. Monitoring the resource
   The condition of the reef walking site and the reaction of the visitors are monitored on a regular basis to determine whether the management objectives are being met. If not the management objectives can be redefined and/or the methods used to implement them can be altered.

The following sections describe survey techniques, and management procedures which can be used in these four stages. They also define criteria and set guidelines that are useful for making comparisons or assessments of reef walking sites.

Since the users of this manual will not all have the same amount of money, time and other resources at their disposal we have, where possible, described a range of techniques that require different levels of investment of time and/or money.

4.3 An essential item of field equipment

A viewing box or a bucket with a transparent bottom is essential for all of the field surveys described in this manual except in calm windless conditions. Even when the water surface on the reef flat is only slightly ruffled identification of coral morphology and accurate counting of other features becomes very difficult if not impossible. Figure 5 illustrates a range of different viewing devices that are suitable for this work.

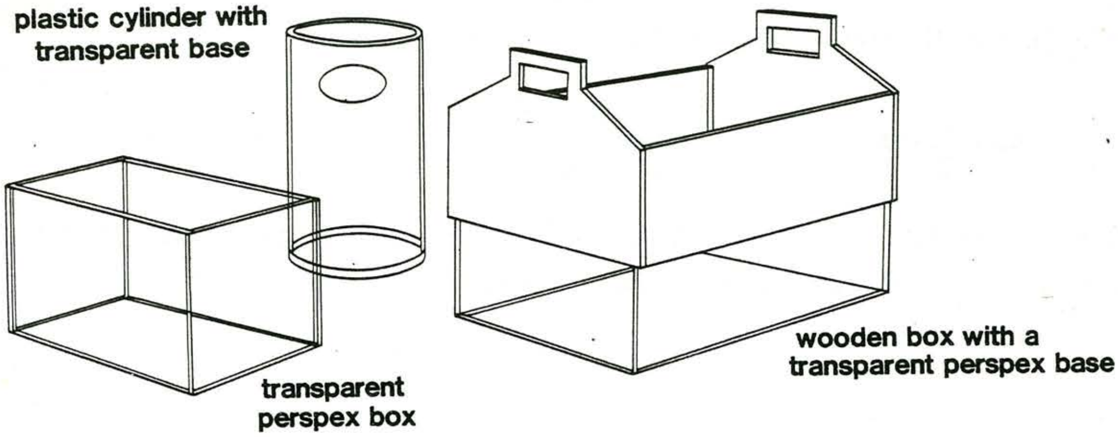


Figure 5 Viewing devices suitable for survey work.

5.0 RESOURCE EVALUATION

5.1 Survey objectives

There are several basic questions which need to be asked when an area is considered for reef walking activities.

They are:

1. How accessible is the area?
2. How many people already use it?
3. How easy is it to walk around in it?
4. What attractions does it contain that will satisfy the reef walkers needs?
5. How vulnerable is the area to trampling damage?
6. What is its present level of damage?

The amount of time which is available for providing answers to these questions will vary enormously in different situations thus we have presented two alternative survey methods in the following section. The first is "a quick look" survey which takes little time and provides general answers to the above questions while the second is a quantitative habitat and movement survey which takes a longer time but provides more detailed and reliable answers. In both cases the preliminary steps of obtaining aerial photographs or maps establishing use levels and checking out accessibility will be the same.

Additionally we have indicated how both methods can be modified to fit different field situations.

5.2 Aerial photographs

A very useful preliminary step is to obtain aerial or satellite photographs of the areas which may be used for the reef walking activities. These can be obtained from the Department of Mapping and Surveying, 288 Edward Street, Brisbane if they are available. They will provide a general picture of the overall topography of the reef flat in terms of the reef crest areas, rubble bands, stretches of sand and channels. Figure 6 shows an example with the various zones marked in. The maps will also suggest possible landing spots for boats on convenient walking routes from adjacent islands or cays.

5.3 Levels of use

Firstly, inquiries at local tourist businesses and resorts will establish if the site is already being used for reef walking. Rough estimates of the average number of reef walkers which use the site each day can then be made on consultation with tour operators or guides. If records have been kept seasonal patterns of use can also be detected.

Also record the number of people and number of craft each time the site is visited and whether it appears deserted, crowded or somewhere inbetween. This will provide additional records to backup the information gained at second hand.

5.4 Reconnaisance of accessibility

If the proposed areas can be reached by walking from an island or cay record:

1. How long it takes to walk to the site?
2. How easy it is to walk there and what obstacles are encountered?

If the proposed area can only be reached by boat record:

1. How long it takes to reach the sites?
2. The location of suitable landing spots?
3. If the landing spots are easy for the boat handler to negotiate and if they are protected from heavy seas?
4. How easy it is for people to get into and out of the boats from the reef flat?

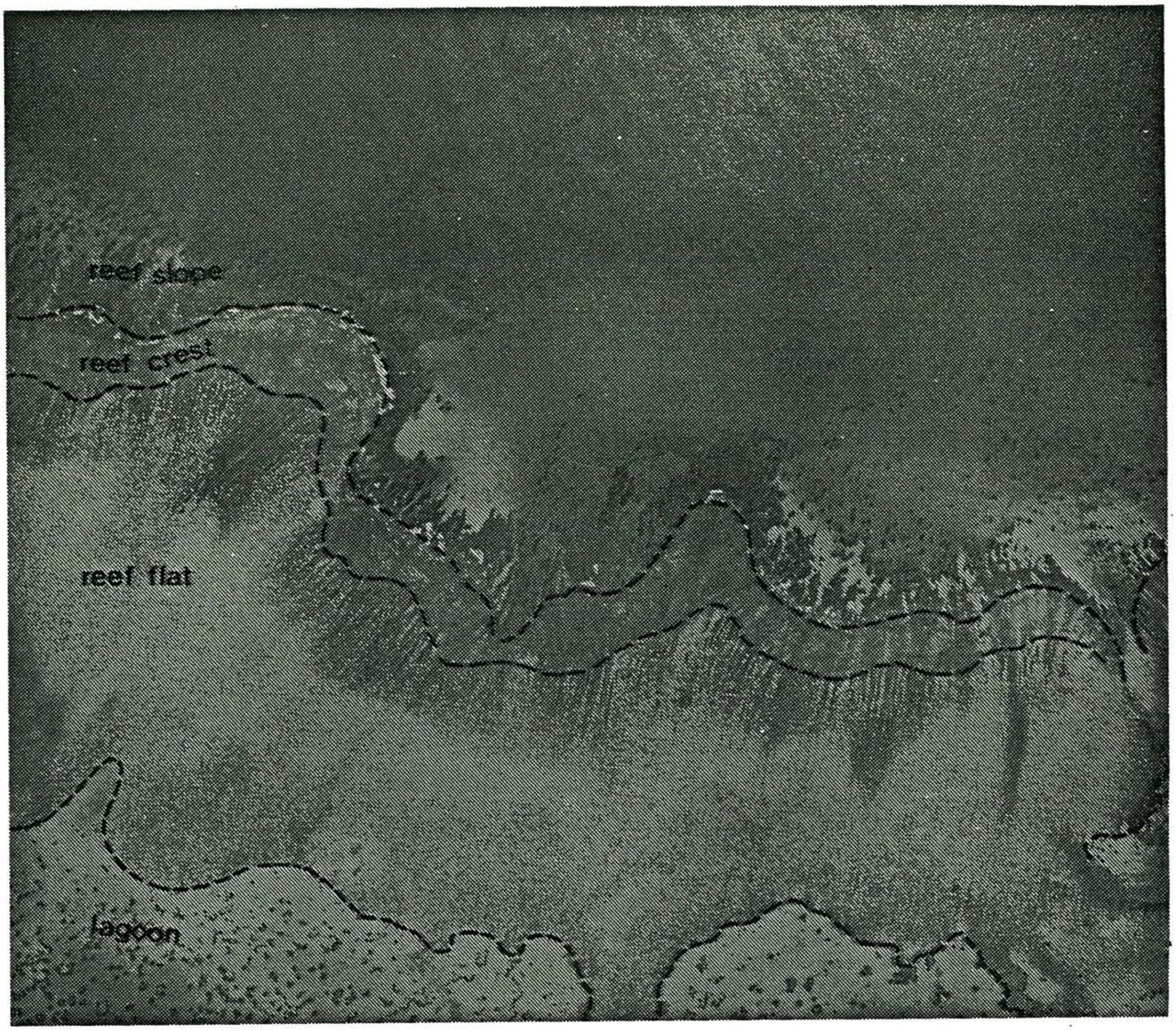


Figure 6 Aerial photograph of a section of Heron Island Reef.

5. If the site can only be reached under certain weather conditions (e.g. dead calm)?
6. Is there any shelter in case of unexpected bad weather?

5.5 <u>A quick look survey</u>

This method is useful if time is very limited as more than one area can be visited in one or two low tide periods.

It is also a useful preliminary to more detailed surveys as it will suggest which areas are worth a closer look and if the more detailed survey in this manual will need modification.

Walk across the length and breadth of the proposed site at least once, and record the following information on the data sheet provided in Figure 7.

1. Number of people in sight
2. Number of boats seen
3. What proportion of the walk was
   (a) difficult to negotiate
   (b) spent on surfaces and/or corals that broke underfoot
4. What proportion of the area do you estimate to be
   (a) bare sand
   (b) sand dotted with isolated outcrops of living and dead coral and/or boulders
   (c) patchwork or sand pools, channels and expanses of coral
   (d) scattered coral rubble, shingle and boulders
   (e) a solid level surface with or without corals
   (f) continuous dead and live corals with/without sand pools
   (See Figure 8. for diagrammatic illustrations of these alternatives)
5. What interesting coral formations did you see (e.g. pools surrounded by branching corals, dense cover of digitate corals on a flat pavement, extensive thickets of corals etc.)?

Figure 7 Quick look survey data sheet.

Site:

1. Number of people:

2. Number of craft:

3. Proportion of walk a. difficult:
   b. broke coral:

4. Proportion of area a. sand:
   b. sand and coral clumps:
   c. patchwork coral/sand:
   d. rubble and boulders:
   e. pavement:
   f. dead and live coral:

5. Coral formations:

6. Mobile animals:

7. Underboulder communities:

8 Live corals:

9. Proportion of colourful corals:

10. Recent physical damage:

Other notes:

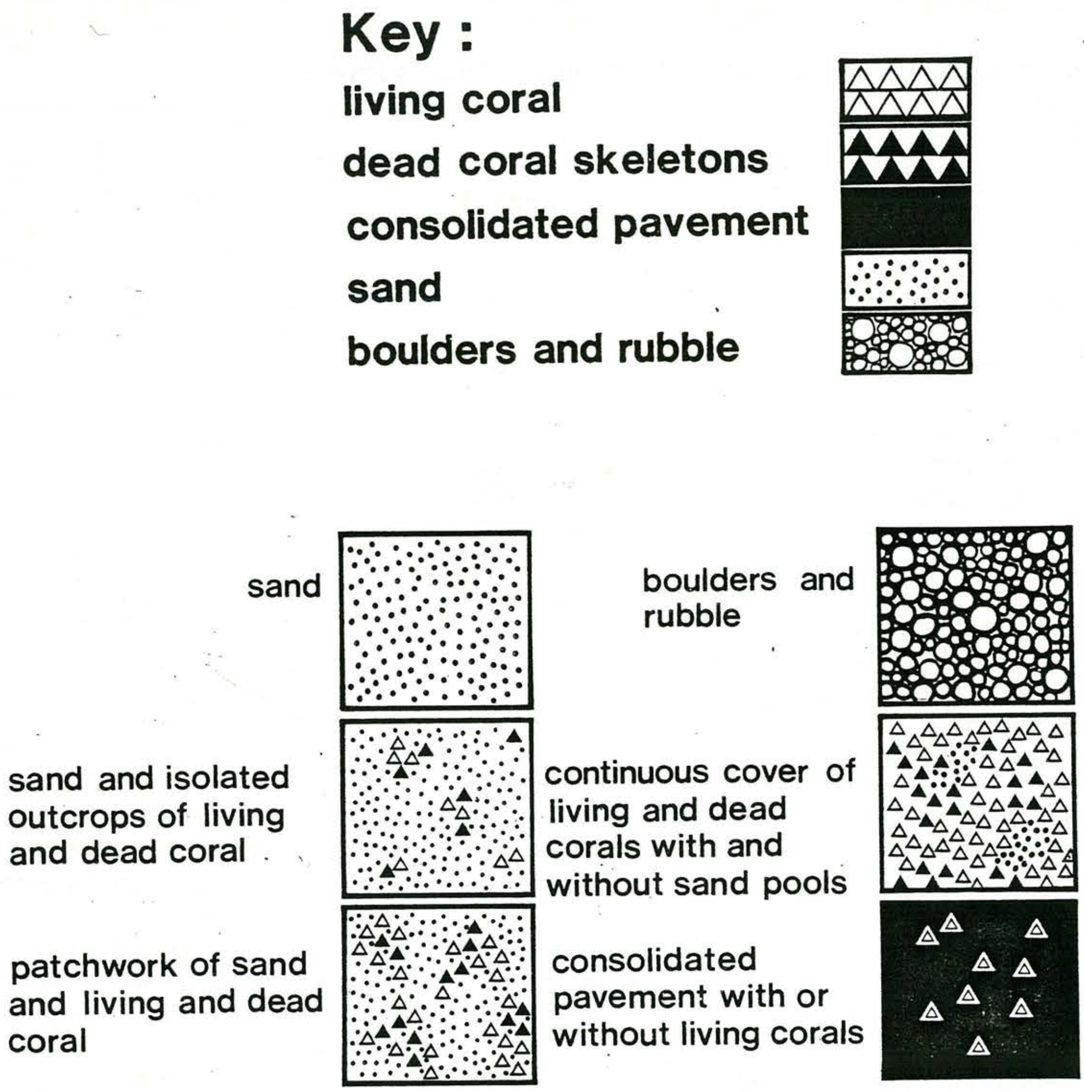


Figure 8 Diagrammatic illustrations of the habitat structures typically seen on reef flats.

Figure 9 Data from two hypothetical quick look surveys.

	Area 1	Area 2
1. Number of people	0	17
2. Number of craft	0	3
3. Proportion of walk		
a. difficult	30%	10%
b. broke coral	40%	20%
4. Proportion of area		
a. sand		20%
b. sand and coral clumps		20%
c. patchwork coral island	50%	30%
d. rubble and boulders	20%	10%
e. pavement	10%	20%
f. dead and live coral	20%	
5. Coral formations	abundant pools surrounded by branching corals	microatolls common good cover of low corals on pavement
6. Mobile animals	fish, molluscs, hermit crabs abundant in pools	lots of sea cucumbers, some seastars
7. Underboulder communities	plentiful	some
8. Live corals	abundant	average
9. % of colourful corals	10%	5%
10. Recent physical damage	some just in the lee of the boulder field	none

6. What interesting mobile animals (seastars, fish, eels, crabs etc.) did you see and how abundant were they (rare, common etc.)?
7. If boulders were present were there colourful or interesting animals underneath them?
8. Were line corals rare, average, abundant?
9. What proportion of corals were brightly coloured?
10. Did you see any signs of recent physical damage such as newly broken branches on colonies, live-broken off coral fragments or overturned colonies?
11. Other observations

Figure 9 shows the data from 2 hypothetical quick look surveys.

Survey Modifications

The information content of this survey can be increased by recording the preceding data for different sections of the surveyed area. For example, the area could be divided into sections along naturally occurring zone boundaries or into quarters (Figure 10). A general picture of the distribution of different features in the area could be gained in this way.

5.6 Habitat and movement survey

This method is appropriate when time is not such a critically limiting factor and when information about the location and extent of different reef flat habitats which cannot be resolved on aerial photographs is desired (e.g. when reef walking routes for guided tours are being planned). It will also produce more complete and accurate data for site evaluation than the quick look survey.

First of all clearly define the area which is being surveyed on a map as shown in Figure 11. Then draw a grid on the map which divides the area into 10 metre by 10 metre squares and mark out an imaginary pathway along the center of each row or column of squares (Figure 11).

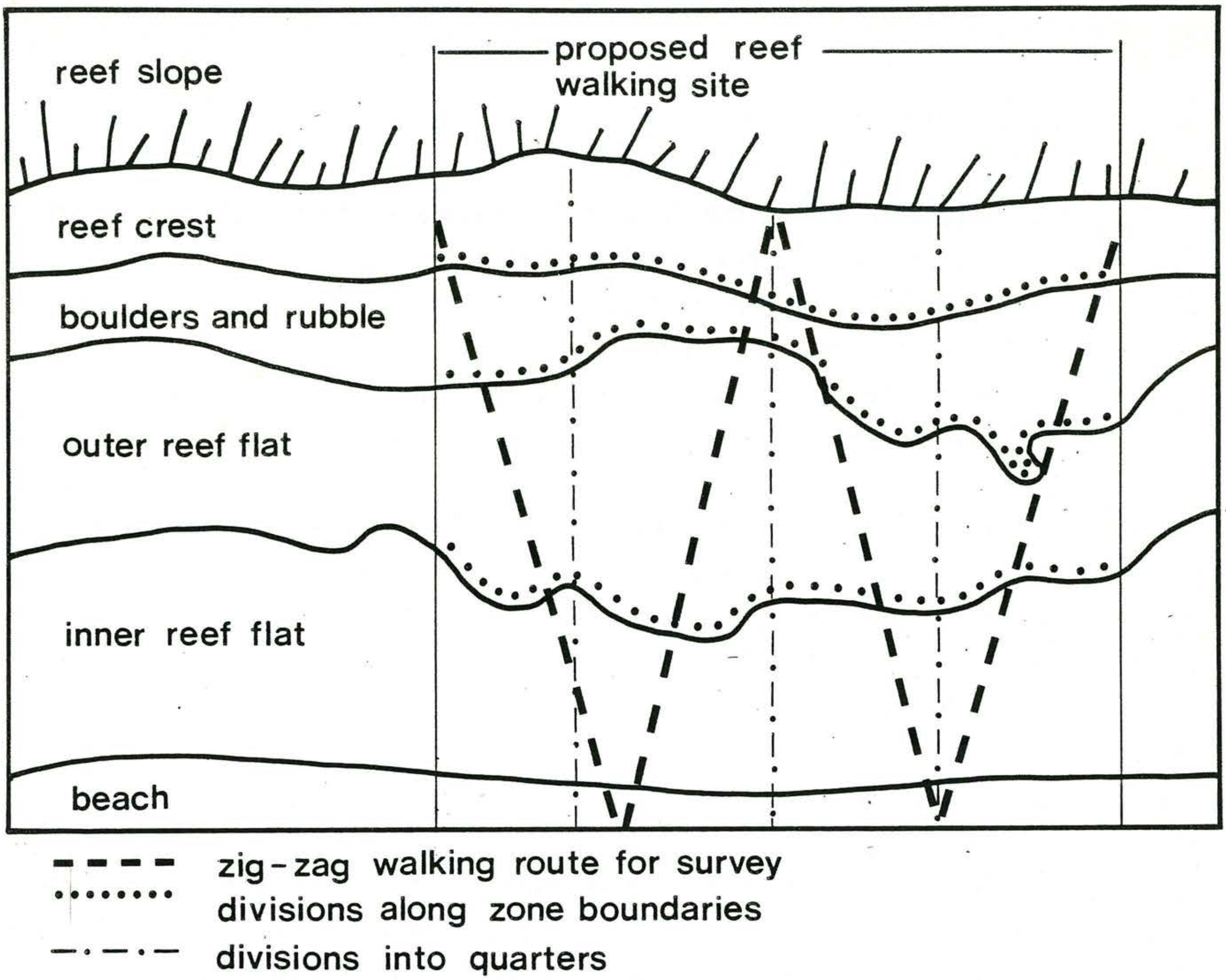


Figure 10 Alternative ways of dividing an area up for the quick look survey.

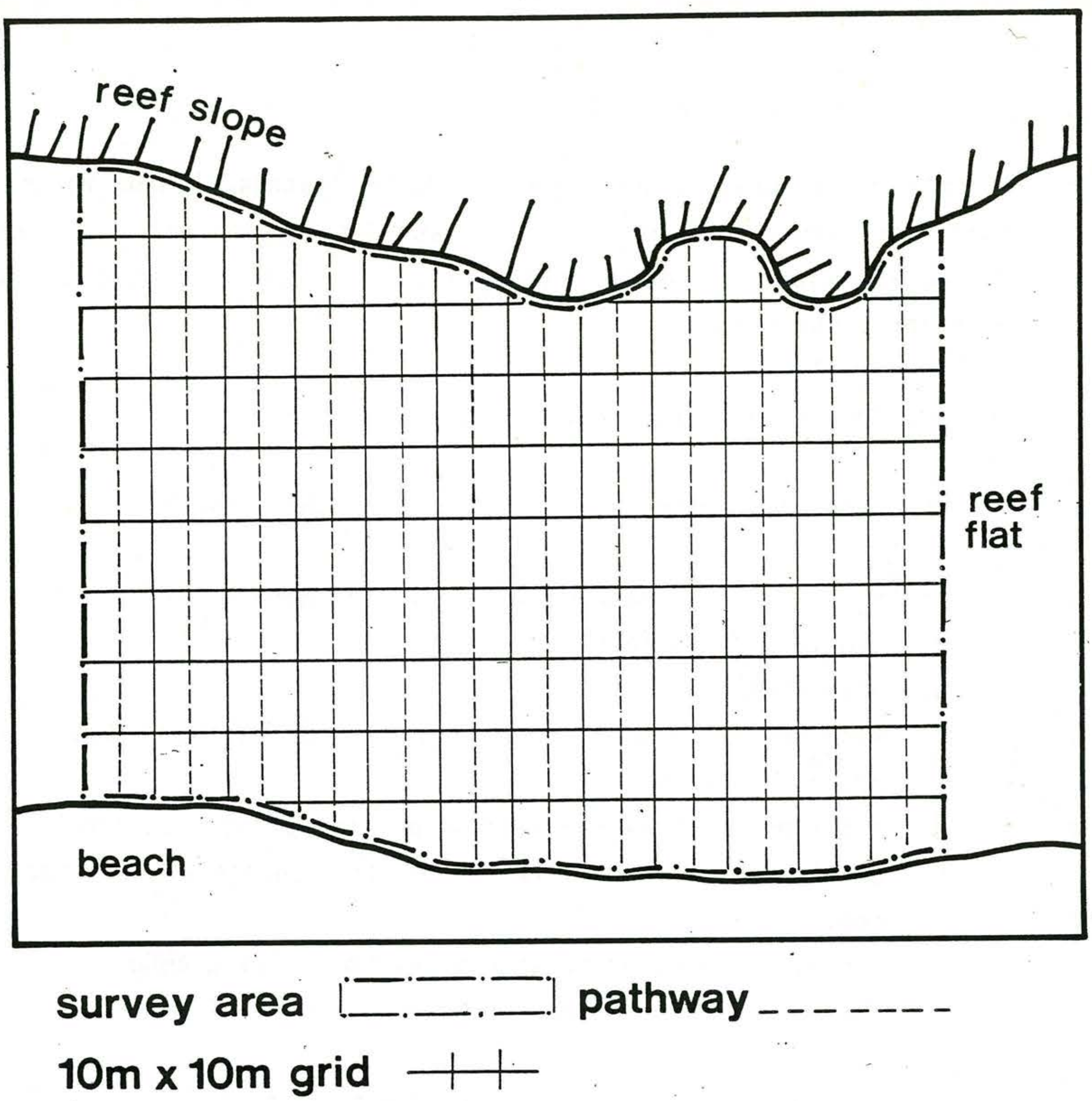


Figure 11 Map divisions for the habitat and movement survey.

In the field walk along each of these 'pathways' and record the following information after each 10 strides (approximately 10 metres) except questions 1 and 2. The data sheet shown in Figure 12 can be used for these records.

1. How many people visited the area during the survey?

2. How many craft were within sight during the survey?

3. Is the 10m x 10m area you just traversed made up of
   a. rubble and boulders
   b. bare sand
   c. sand dotted with isolated outcrops of living and dead coral and/or boulders
   d. a patchwork of sand and areas of living and dead corals
   e. continuous cover of living and dead corals with/without sand pools
   f. consolidated pavement with or without living corals
   (See Figure 8 for illustration)

4. a. Is the area impassable due to such features as very deep water, strong tidal currents or exstensive thickets of pointed staghorn corals?
   b. Is the area passable but rough going due to such features as unstable or very uneven surfaces and coral colonies?
   c. Is the area easy to walk through?

5. What proportion of your footsteps broke live or dead coral in the last 10 metres:
   a. none
   b. less than half
   c. more than half

6. Are the coral colonies in the 10m x 10m area you have just traversed
   (a) mainly low and compressed with little vertical growth
   (b) mainly high and not compressed with marked vertical growth.

Figure 12 Habitat and movement survey data sheet.

1. Number of people: 2. Number of craft:

Grid number:										
3. Structure of habitat										
(a) rubble and boulders										
(b) bare sand										
(c) sand and isolated clumps										
(d) sand and coral patchwork										
(e) continuous corals										
(f) consolidated pavement										
4. Movement										
(a) impassable										
(b) rough going										
(c) easy walking										
5. Trampling damage										
(a) none										
(b) < 1/2 footsteps										
(c) > 1/2 footsteps										
6. Coral type										
(a) low and compressed										
(b) not compressed										
7. Coral cover 0%										
<10%										
10-15%										
>50%										
Algal cover 0%										
<10%										
10-15%										
>50%										
8. Notes on interesting features										
9. Broken fragments										
(a) none										
(b) few										
(c) many										

7. Is (a) coral and (b) algal in the 10m x 10m area you have just traversed

   1. absent: 0% cover
   2. sparse: less 10% cover
   3. intermediate: 10% - 50% cover
   4. dense: over 50% cover.

8. List the interesting features in this area which would be attractive to a reef walker e.g. thicket of bright green branching coral, anemone with clown fish, giant clams.

9. Were broken off line coral fragments and fractures in coral colonies exposing white skeleton

   (a) absent
   (b) present but in low numbers, no more than 1-2 per sq. metre
   (c) present and very abundant, at least 2 per sq. metre.

   Figure 13 shows a filled out data sheet from a hypothetical reef walking area.

The data collected from this survey can be processed and presented in two ways for the purposes of site evaluation.

1. Percentage Composition

Firstly calculate what % of the surveyed area was made up of the various characters (e.g. bare sand, easy to walk on etc.) that were scored during the survey. This is done using the following formula.

$$\frac{\text{Number of 10m x 10m areas scoring a character}}{\text{Total number of 10m x 10m areas}} \times 100$$

example: total number of 10m x 10m areas = 50
Number of areas scored as sand bottom = 20

Figure 13 A filled out data sheet from a hypothetical habitat and movement survey.

1. Number of people: 15   2. Number of craft: 1

Grid number:	1	2	3	4	5	6	7	8	9	10
3. Structure of habitat										
(a) rubble and boulders							X	X	X	
(b) bare sand										
(c) sand and isolated clumps	X	X	X							
(d) sand and coral patchwork				X						
(e) continuous corals					X	X				X
(f) consolidated pavement										
4. Movement										
(a) impassable										
(b) rough going					X	X				
(c) easy walking	X	X	X	X			X	X	X	X
5. Trampling damage										
(a) none	X	X	X	X			X	X	X	X
(b) < 1/2 footsteps					X					
(c) > 1/2 footsteps						X				
6. Coral type										
(a) low and compressed										X
(b) not compressed	X	X	X	X	X	X				
7. Coral cover 0%	X						X	X	X	
<10%		X	X							X
10-15%				X	X	X				
>50%										
Algal cover 0%										
<10%										
10-15%										
>50%										
8. Notes on interesting features					lots of ornate coral colonies		animals under boulders interesting			
9. Broken fragments										
(a) none	X	X	X	X	X		X	X	X	X
(b) few						X				
(c) many										

$$\frac{20}{50} \times 100 = 40\%$$

Therefore 40% of the survey area had a sand bottom.

Figure 14 shows the results of such calculations for two hypothetical reef flat areas which were surveyed using the preceding method.

2. Distribution of the characters

Secondly a series can be drawn of maps showing the distribution of the various characters. This is done by filling in each 10m x 10m square on the map grid with a distinctive visual code which represents the specific character which was scored in that square.

It is not necessary to draw a separate map for each character as several characters can be grouped together as suggested in Figure 15. Figure 16 shows a series of maps drawn for a hypothetical reef flat area using the groupings and codes shown in Figure 15.

Survey Modifications

This survey can be altered in two major ways.

1. The accuracy, resolution and duration of the survey can be increased or decreased by drawing a smaller (5m x 5m) or larger (20m x 20m) grid. The size of the grid chosen will be a compromise between accuracy and the time that can be spent on the survey.

2. Characters can be added or deleted from the survey as it is presented in this manual according to the peculiarities of the areas to be surveyed. For example the site may have large areas with a distinctive sand and soft coral patchwork but no boulders or rubble. Such things could be established in a preliminary

Figure 14 The results of two hypothetical habitat and movement surveys.

	Percentage of area with feature	
	Area 1	Area 2
Structure of habitat		
a. rubble and boulders	10	
b. bare sand	20	20
c. sand and isolated clumps	20	40
d. sand and coral patchwork	20	10
e. continuous corals	20	30
f. consolidated pavement	10	
Movement		
a. impassable	5	
b. rough going	25	20
c. easy walking	70	80
Trampling damage		
a. none	50	80
b. less ½ footsteps broke coral	20	10
c. more ½ footsteps broke coral	30	10
Coral type		
a. low and compressed	30	
b. not compressed	40	80
Coral cover 0%	40	30
<10%	10	30
10-50%	40	40
>50%	10	
Algal cover 0%	50	30
<10%	40	20
10-50%	10	50
>50%		
Interesting features	numerous: see data sheet	a few
Broken fragments		
a. none	70	50
b. few	30	30
c. many		20

quick look survey and the data sheets for the more detailed survey modified accordingly.

5.7 Criteria for evaluation

Once the various sites have been surveyed by either method their suitability for reef walking activities can be assessed and compared using the following criteria.

1. Accessiblity

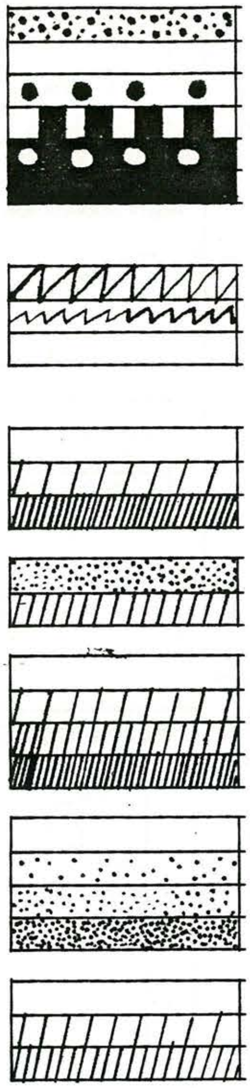
A reef walking area must be accessible to the people who use it. e.g. (1) A very long walk over difficult unstable surfaces in deep water would clearly be undesirable whereas a 5 or 10 minute walk over sand or on a platform of solid dead coral would score favourably; (2) A landing site which is protected from rough seas, can be reached in most weather and is easy to negotiate for both boat handlers and visitors would be more desirable than a landing site which can only be reached in calm weather and is difficult for the visitors to step onto from the boat.

The age and physical skills of the visitors also need to be considered when assessing this aspect of the site. Whereas younger people would enjoy a vigorous wade or the excitement of swimming from the boat to the reef edge a more elderly tourist would not.

2. Usage

The desired level of use will depend on the type of visitor. If the majority of people who visit the site are expecting to see an environment with a wilderness character the presence of others will interfere their experience. Under these circumstances the less well patronized a site the better it is for reef walking. If, on the other hand, the majority of people are expecting a

Figure 15 Visual codes and groupings for the characters scored in the habitat and movement survey.



Structure of habitat

rubble and boulders
bare sand
sand and isolated clumps
sand and coral patchwork
continuous corals
consolidated pavement

Movement

impassable
rough going
easy going

Trampling damage

none
< 1/2 footsteps broke coral
> 1/2 footsteps broke coral

Coral type

low and compressed
not compressed

Coral cover

0%
<10%
10-50%
>50%

Algal abundance

0%
<10%
10-50%
>50%

Broken fragments

none
few
many

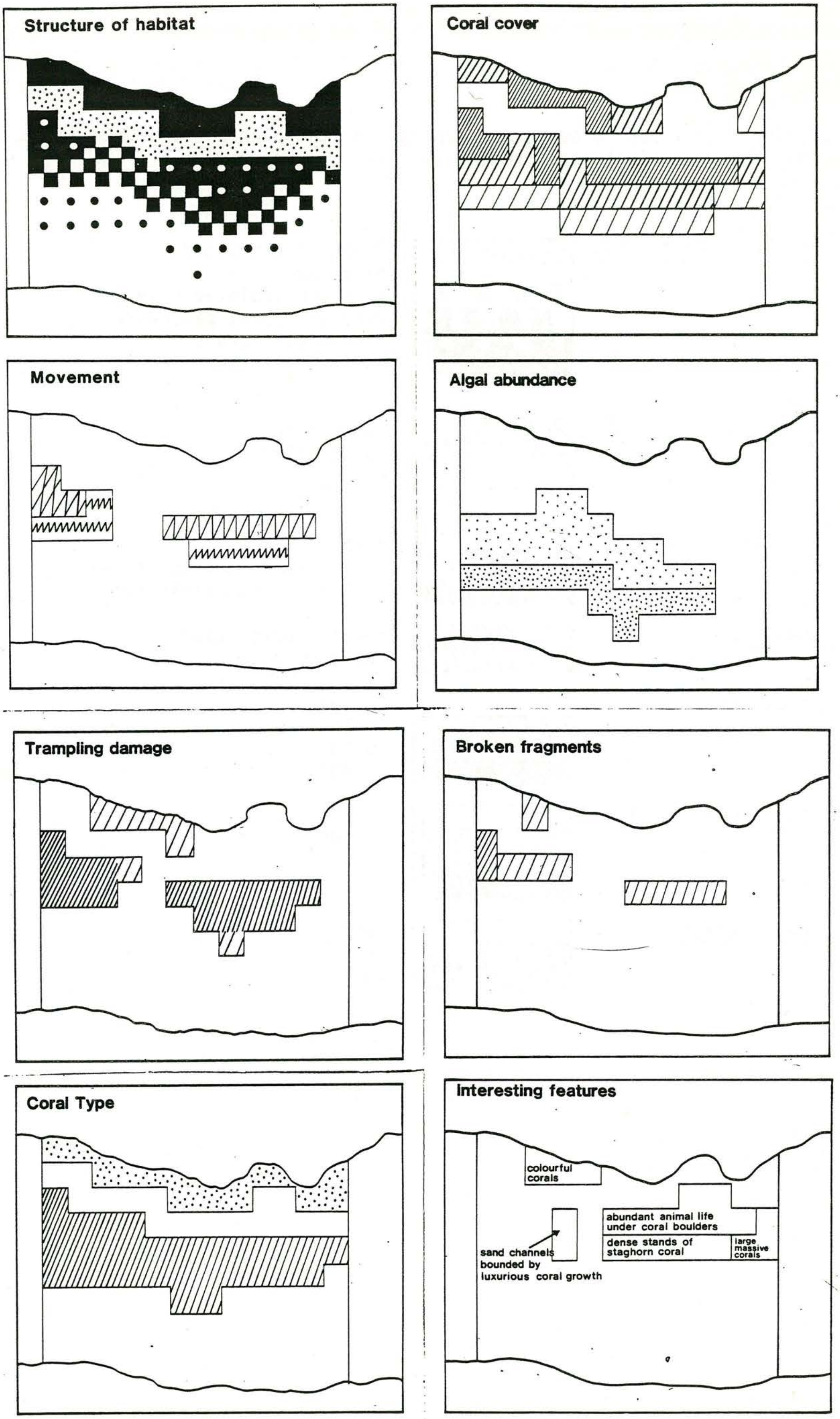


Figure 16 Maps showing the distribution of the characters scored in a hypothetical habitat and movement survey.

natural looking environment which also has a holiday atmosphere the presence of other reef walkers will add to the experience rather than detract from it. In these circumstances a site which is regularly visited but not overcrowded would be most desirable.

3. Ease of movement

Reef walkers need to be able to move freely and easily through the site e.g. a site which contains few obstacles such as unstable surfaces and extensive continuous thickets of staghorn coral would be more suitable for reef walking than a site which had extensive areas of such obstacles.

4. Attractions

A reef walking area must have biological features which are attractive to the visitor. These attractions are many and varied however, in general, ornate and luxuriant coral forms, bright colours, exotic tropical animal life and a high variety of habitats are all desirable.

The more natural attractions the site has the more suitable it is for reef walking.

5. Vulnerability to damage

The less susceptible a site is to damage caused by human trampling the more suitable it is for reef walking. An area where a large amount of substrate material and living coral is broken underfoot during the evaluation survey is likely to be more vulnerable to trampling damage than an area where little of this occurs. If a site is easily damaged it is likely to change as a result of reef walking and loose those characters which made it attractive to visitors in the first place.

6. Damage levels

Obvious signs of trampling damage such as broken up coral colonies decrease a sites suitability for reef walking as they lessen its natural unspoilt appearance. The less damage found in a site the more suitable it is for reef walking.

5.8 A note on carrying capacity

Carrying capacity is defined as the maximum level of recreational use that can be accommodated in an area before an unacceptable or irreversible change occurs in the environment. Quantitatively the level of use can be expressed in terms of the number of people per unit area per unit time.

At the present stage of our knowledge the carrying capacity of a reef flat site which contains a complex of different coral communities cannot be accurately estimated on the basis of a resource evaluation survey. Close monitoring of environmental changes associated with changing levels of use are necessary (See Section 8.5).

However Kay and Liddle's (1984a) long term trampling experiment suggests that the carrying capacity of a coral community made up of low and flattened colonies on a solid pavement of dead coral will be in the order of 100-200 people/100m^2/week and that of a community made up of taller three dimensional colonies and solid and honeycombed remains of dead coral will be in the order of 5-10 people/100m^2/week. Any areas within a surveyed site that fit either of these descriptions are likely to have similar carrying capacity.

This information can be used as a guideline for setting preliminary use levels at a site, choosing the routes for guided tours and paths and the installation of walkways.

6.0 MANAGEMENT OBJECTIVES

6.1 Acceptible environmental changes

There are two main factors to consider when determining what will be acceptible environmental changes in a reef walking site. They are:

(a) The expectations and objectives of the users

As described in section "What do people want to see" all three user groups, tourists, educational groups and scientists, prefer to see or operate in an unspoilt natural environment. Additionally tourists in particular expect to see a variety of exotic features such as brightly coloured fish and ornate corals which characterize the coral reef environment.

(b) The resilience of the area (that is the ability of an area to recover after damage).

The growth rates of different forms of coral vary enormously therefore reef flat sites of different composition are unlikely to regenerate at the same rate after a given amount of reef walking damage.

These considerations suggest three general criteria for the determination of acceptible environmental change.

i Visual evidence of physical damage should be minimal.

ii Reduction in the numbers and variety of the exotic features which attract tourists should be prevented or minimized.

iii Reduction in the cover of live coral should not be permitted to exceed that amount which could be regrown during an off peak season or reasonable period of closure.

Using these 3 criteria as a guide more specific management objectives can be set to prevent unacceptible environmental degradation.

For example:

1. The numbers of (a) visible breaks in live coral colonies
   (b) broken off live coral fragments
   (c) overturned colonies

   are to be kept below twice their pre-reef walking numbers.

2. A reduction in the density of anemones with resident clown fish is not be greater than one half of their pre-reef walking numbers.

3. The percentage cover of massive corals should not decrease by more than 5% before the six monthly closure period.

Such objectives will depend largely on the subjective judgement of the management personnel in the field as to what feature or features will be appropriate indicators of environmental change at a specific site. Section 8.0 "Resource Monitoring" describes monitoring techniques which can be used to check if the objectives are being met.

6.2 Interpretive services

Interpretive services can be used to fulfill any one or all of the following three objectives.

1. Enhancement of the reef walking experience
2. Visitor safety
3. Modification of reef walking behaviour in order to decrease resource degradation.

7.0 IMPLEMENTATION OF OBJECTIVES

7.1 General approach

Broadly speaking there are two approaches which can be used in the formulation of management techniques.

They are:

(a) Control visitor numbers and/or guide or influence visitor behaviour
(b) Alter the environment so it is less susceptible to damage.

These two approaches are not mutually exclusive and often underlie the same management technique as shown in Figure 17 which lists the management procedures we have described in this manual.

Some of these techniques also function as interpretive services (see Figure 17) where information is provided to enhance visitor enjoyment and safety.

7.2 Guided tours

Guided reef walking tours are best conducted over a known route which is easy to negotiate and offers a variety of interesting features for the visitor. These routes can be selected using information from the original site surveys and field reconnaisance. Figure 18 shows a hypothetical route and Figure 19 lists some guidelines for choosing a suitable path.

The role of the guide is, firstly, to lead the group along the route and enhance their enjoyment and understanding of the environment by pointing out and explaining features along the way. Secondly, the guide can also influence peoples behaviour by explanation and suggestion in order to minimize trampling damage and increase visitor safety.

Figure 17 Management techniques and their implications described in the manual

Technique	Visitor Control	Alter Environment	Interpretive Service
Guided tours	X		X
Information leaflets	X		X
Films and videos	X		X
Pathways	X	X	
Elevated walkways	X	X	
Transplantation of corals		X	
Limiting access	X		
Closed seasons and rotational use	X		

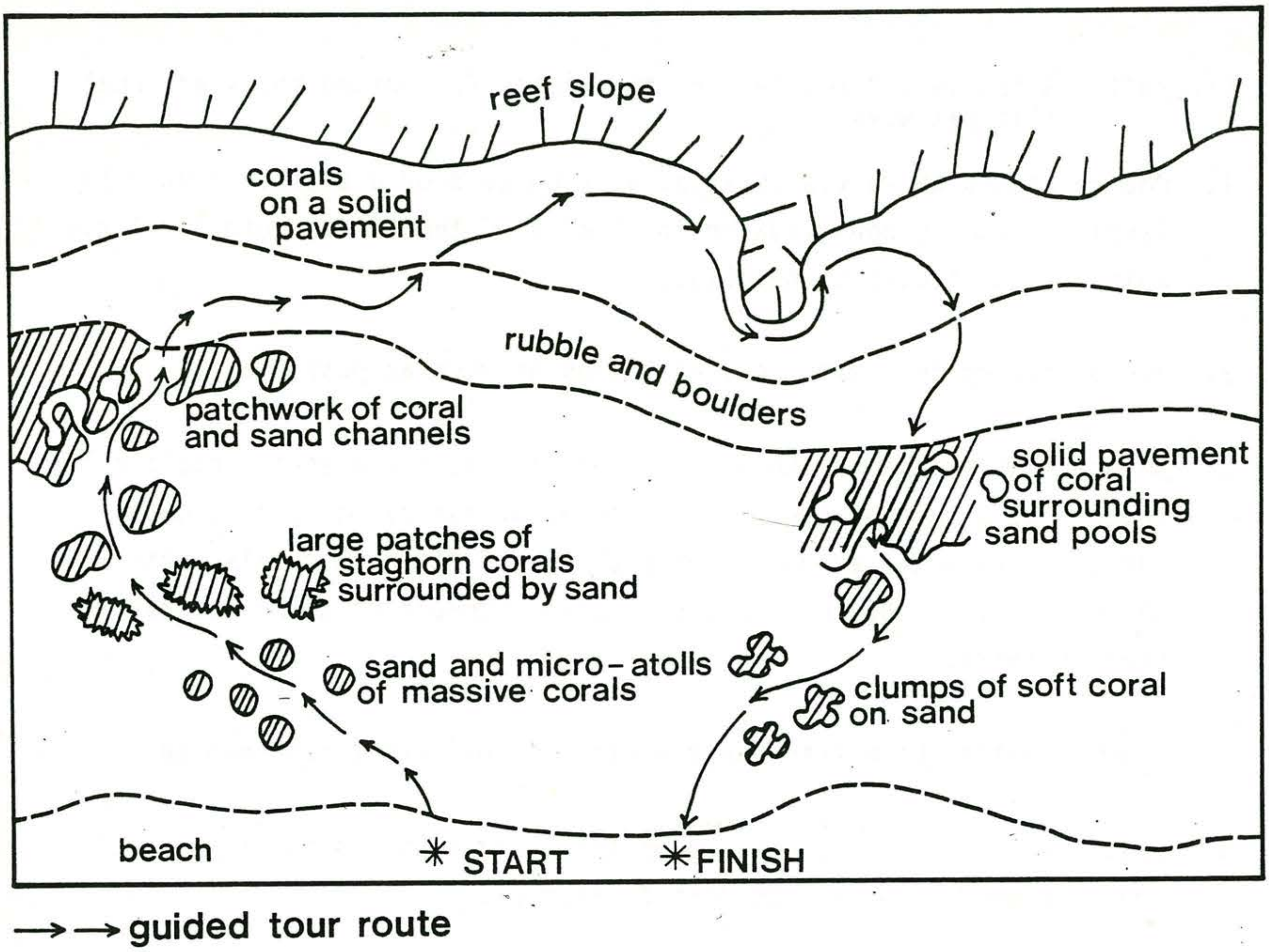


Figure 18 The route of a hypothetical guided tour.

Figure 19 Guidelines for selecting the routes for guided tours and reef flat pathways.

1. Choose routes where visitors can walk on sand or a stable relatively level surface on consolidated coral most of the time, avoid localities which are difficult to negotiate.

2. Avoid walking on living coral colonies as much as possible.

3. Select routes adjacent to as many interesting features as possible (e.g. routes through sand pools flanked by luxurious coral growth, paths skirting the edges of dense stands of staghorn corals, paths through expanses of coral boulders with interesting animal communities beneath them).

4. Choose routes which traverse a variety of different reef habitats.

5. Position the beginning and end of the route so it is easily accessible from accommodation or transport facilities.

6. Choose routes which can be used in most weather conditions.

7. Avoid areas which are only negotiable at very low spring tides, choose a route which can be used at most low tide levels.

7.3 Information leaflets

As the name suggests such leaflets are designed to inform the visitor about the reef flat which they will be visiting. Some basic guidelines for their contents are:

(1) Clear and accurate illustrations and explanations of the major interesting features of the reef flat.

(2) A map showing the location of different zones and habitats, suggested walking routes and especially interesting features.

(3) Information about personal safety (e.g. tides, poisonous animals and unstable surfaces).

(4) Information about trampling damage and ways to avoid it (e.g. illustrations of different coral forms indicating their vulnerability to trampling damage and which ones to avoid walking on).

These leaflets can be handed out on boats or aeroplanes bound for reef walking sites and made available to tourists and others at resorts and national park offices and centres on the Great Barrier Reef.

7.4 Films and videos

Films and videos fill essentially the same role as information leaflets, however, they have extra entertainment value which makes them a doubly useful commodity for the tourist industry. Details of their production are beyond the scope of this manual however they should provide accurate information for the benefit of the audience and ultimately the environment they portray.

7.5 Pathways

Pathways can be used to aleviate the trampling pressure on a reef flat by encouraging people to follow a planned route rather than wandering at random over vulnerable reef flat habitats. The guidelines listed in Figure 19 for choosing the route of a guided tour are also applicable for a pathway.

The route can be marked out in the field using numbered posts or bouys and a self guiding "nature trail" pamphlet can be made available for would be reef walkers. The pamphlet should contain a map of the pathway and information about features along the way (also see guidelines for information leaflets in Section 7.3).

Creating pathways on a reef flat could also involve cutting through dead and living corals to link wadeable pools, removing treacherous stretches of dead coral which are apt to collapse when stepped on, cutting steps were appropriate, or transplanting coral.

7.6 Elevated walkways

Confining visitors to elevated walkways over a reef flat will remove trampling pressure from an area completely. This approach is fairly extreme and would only be appropriate for sites which are regularly visited by thousands of people a week and would otherwise be decimated.

The construction of a walkway is an engineering problem beyond the scope of this manual, however, a major factor in their location would be the close proximity of interesting reef flat habitats containing a wide variety of corals and other organisms which could be viewed from the walkways. Some of the guidelines for a guided tour route (Figure 19) would also be relevant here.

7.7 Transplantation of corals

Transplantation of corals can be used to increase the aesthetic value of a reef walking area, route or path by increasing the variety and cover of living corals and providing new habitats for mobile animals such as fish, eels, crabs and shellfish. It can also be used to speed the recovery of a degraded reef flat during closed seasons or to compensate for the ongoing trampling damage in an area which is regularly used by reef walkers.

Some basic guidelines for the transplantation process are:

1. Provide a stable, permanently submerged support for the transplanted colonies to grow on (e.g. old coral boulders, cement blocks or bricks and metal or wire frames). The transplanted corals can be fixed to these supports by fishing line until sufficient coral growth occurs to permanently anchor the new colonies.

2. The corals must be positioned so that they do not risk smothering by sand or exposure during low tide.

3. The corals should be kept covered with sea water during the transplantation process to maximize survival rates.

4. Corals should be selected from habitats resembling those they will be transplanted to.

5. Broken off branches of staghorn corals over $8cm^{-m}$ overall length, survive transplantation well and grow rapidly. Massive forms grown much more slowly and survive best if whole colonies are transported.

7.8 Limited access

Trampling damage can also be ameliorated or avoided by limiting access to reef walking areas thereby restricting the number of people who visit them.

If the reef walking area can only be reached by boat this can be achieved by limiting the number of craft which visit the area each day. In other circumstances issuing a limited number of reef walking permits could effectively limit the number of reef walkers.

Limiting access presupposes a knowledge of the carrying capacity of a site which can only be estimated very approximately by initial surveys (Section 5.8). However, these first very broad estimates can be refined during the monitoring and use of an area (See Section 8.5) so this technique will be most reliable in an area that has been opened for reef walking and studied for some time.

7.9 Closed seasons and rotational use

Closed seasons and rotational use schemes involve periods of intense use where damage may occur followed by rest periods of no, or very limited, use where the damage is repaired. In either case reef walking activities can be stopped in an area by encouraging people to keep to marked paths, to use alternative reef walking sites, by limiting transport to isolated reefs or reef areas and providing guided tours.

The duration of the use and rest periods can be determined using a monitoring scheme. Once the environmental changes become unacceptable according to management objectives the area can be closed until regeneration returns the site to an acceptable state.

8.0 RESOURCE MONITORING

8.1 The monitoring schedule

Ideally all monitoring schemes should begin before the site is opened to reef walking. One or more "before" surveys establish what the undisturbed or natural state of the site is like and provide a standard to which the results of subsequent surveys can be compared.

The intervals between the surveys of a monitoring scheme will depend on the time and resources available, however, we suggest an optimum of six months until it has been confidently established that management objectives are being met. After this the intervals can be extended to a year or more unless use patterns change dramatically and more frequent monitoring is needed to detect rapid degradation before it goes too far.

In this section we have described methods for the monitoring of

1. Mechanical damage
2. Coral composition
3. Level of use

and conclude with a comment on carrying capacity.

8.2 Assessment of damage

Reef walking can cause the following four types of mechanical damage in a coral community.

1. Broken off fragments of living coral.
2. Visible unhealed fractures in coral colonies.
3. Overturned coral colonies.
4. 'Ditches' through stands of branching corals.

The abundance of each of these features can be recorded using the following survey method.

Mark at least four equally spaced parallel transects on a map of the area as shown in Figure 20. In the field lay a tape measure or rope transect line (rope knotted or marked at regular intervals e.g. one metre) along each transect in turn and record the numbers of each of the first three features that occur within a sample area one metre by four metres centred over the path every five metres (Figure 20). A wire or metal square, one metre by one metre (a metre square quadrat) can be used to delineate this area. Also record the approximate position, orientation and length of any ditch seen during the survey. Figure 21 shows two hypothetical data sheets from such a survey.

The average density (numbers/m^2) of the first three features at the site can be estimated from this data and graphically presented as in Figure 22. The ditch data can be presented visually on a map and/or in terms of number and average length (Figure 22).

The survey can be modified extensively by collecting data at shorter or longer intervals, increasing the number of transects across the site and changing the size and shape of the sample areas. As a general guide the higher the number of individual sample areas and the greater their size the more accurate and reliable the results.

If tape measures and quadrats are not available this survey can be carried out in a rough and ready way by pacing out the distances between sample points and estimating quadrat size by eye.

8.3 Assessment of coral composition and cover

Figure 23 lists the different coral shapes and substrate types that are commonly seen on coral reef flats and their relative susceptibility to trampling damage (See Kay and Liddle 1984a and b for further discussion). Changes in the composition of a reef walking site can be monitored using this scheme as a base.

Mark at lest ten equally spaced, parallel, transects on a map of the area as shown in Figure 20. In the field lay a tape measure or rope

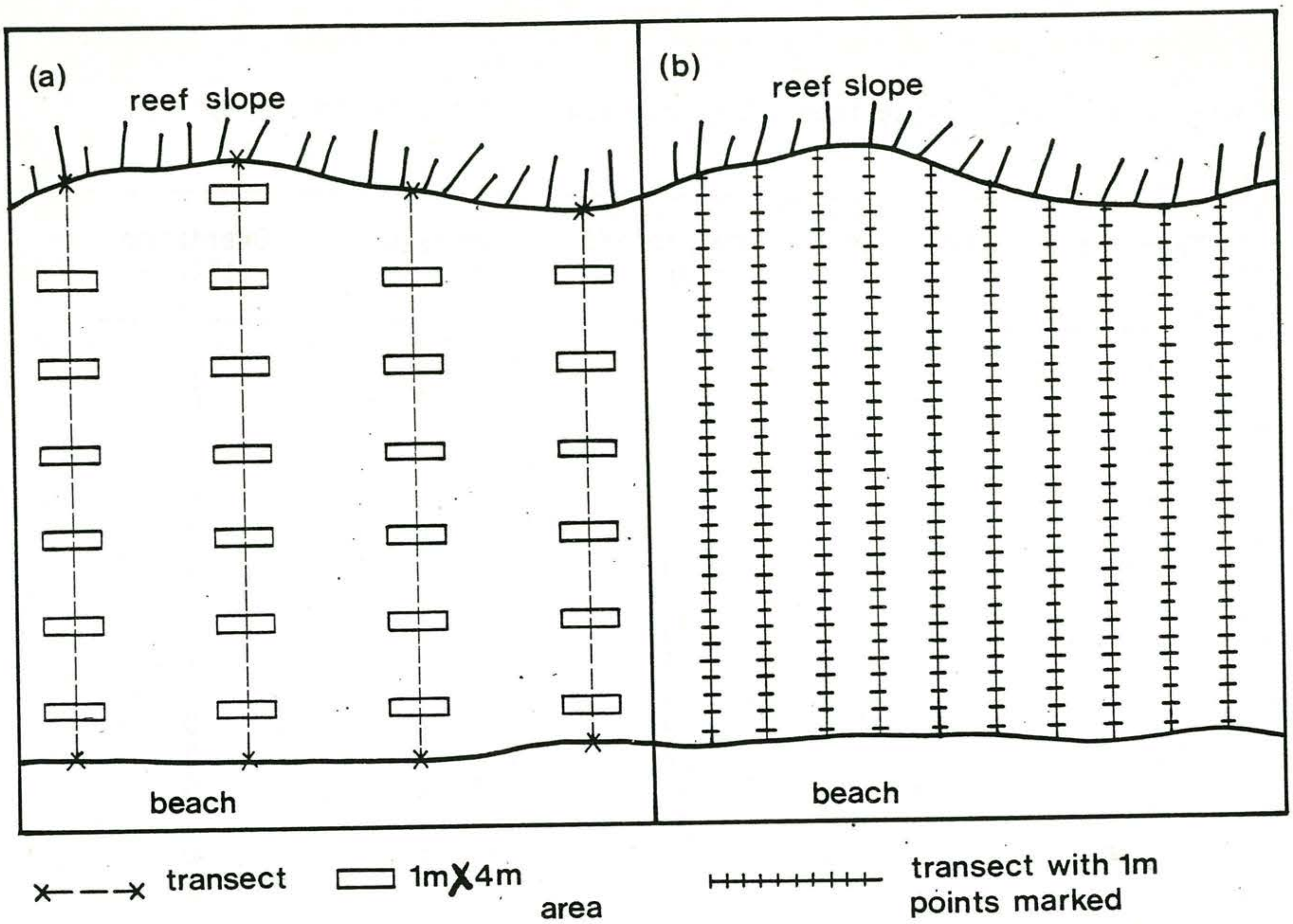
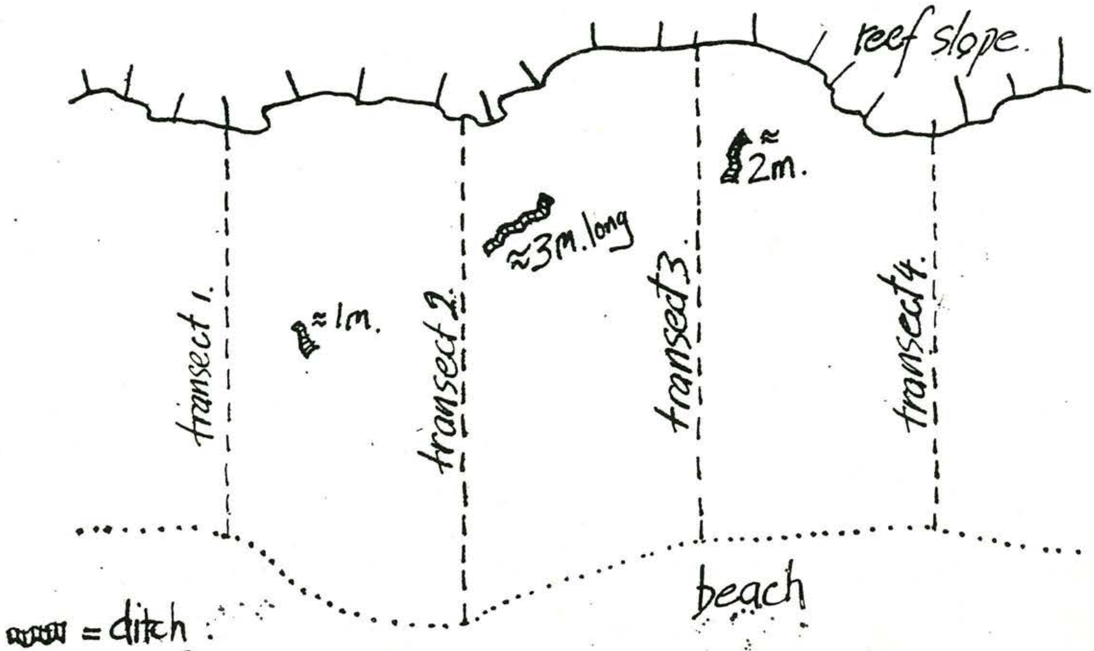


Figure 20 Transect layouts for assessing (a) damage and (b) coral composition and cover on a reef walking site.

Figure 21 Data sheets from a hypothetical damage assessment survey.

Transect	Quadrat	Broken off fragments	Unhealed fractures	Overturned colonies
1	1	0	0	1
	2	0	0	0
	3	0	0	2
	4	0	0	1
	5	6	3	0
	6	7	10	0
	7	0	1	0
2	1	0	0	0
	2	1	2	1
	3	1	3	0
	4	2	0	0
	5	14	12	3
	6	11	6	0
	7	30	5	1
	8	1	0	0
	9	2	0	0
3	1	0	0	0
	2	0	0	0
	3	0	0	0
	4	0	0	0
	5	0	0	0
	6	7	2	0
	7	5	1	1
	8	2	3	0
4	1	0	1	0
	2	1	0	0
	3	1	0	0
	4	0	4	0
	5	1	0	0
	6	0	0	0



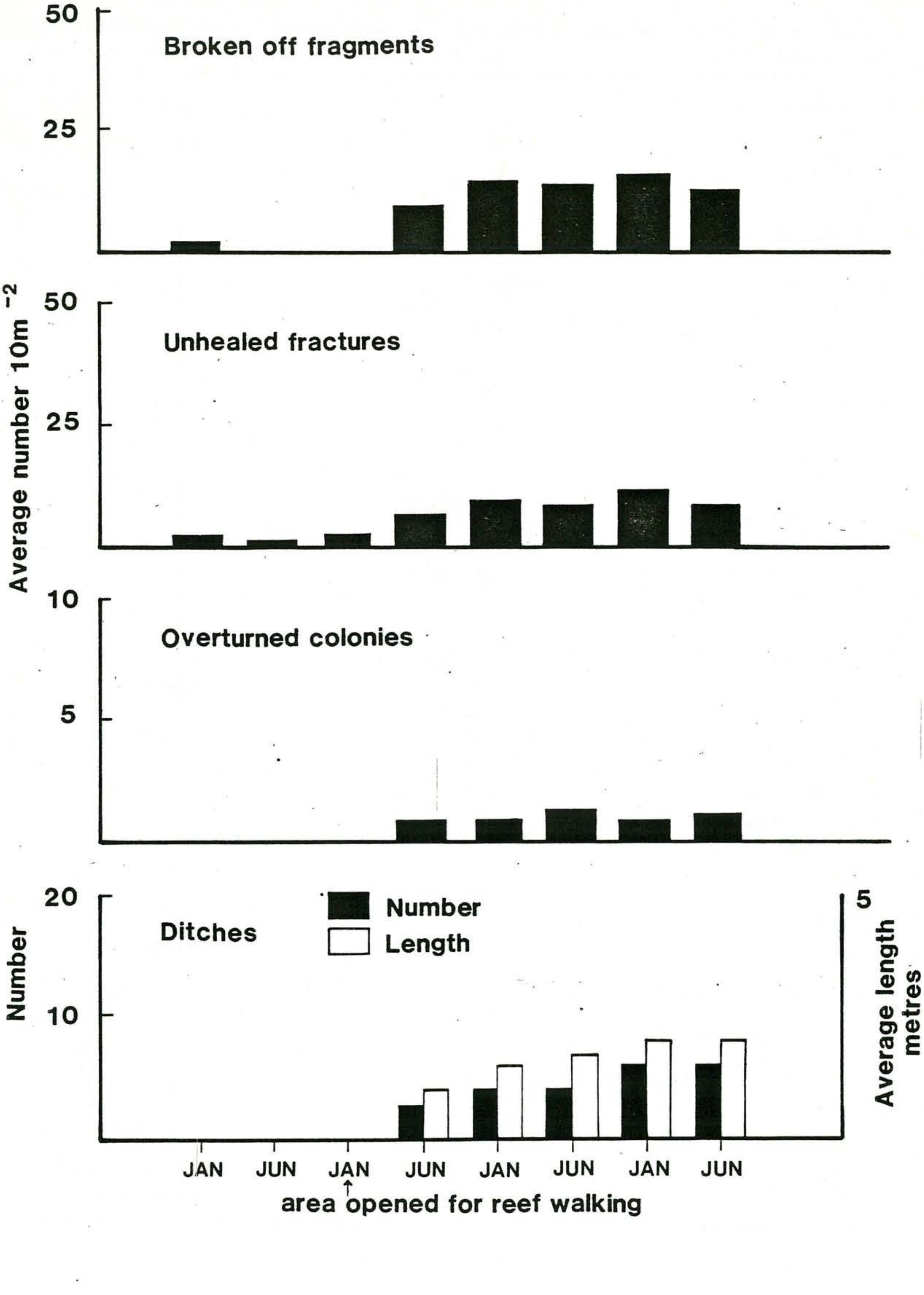


Figure 22 Results from a damage assessment monitoring scheme.

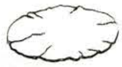
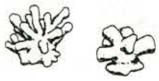
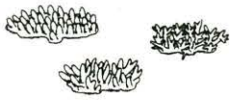
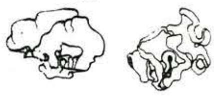
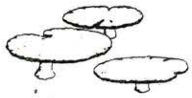
Morphological categories	Typical colonies	Vulnerability to trampling damage
massive		very low
encrusting		
wedge, blade like or thick knotty branches		
digitate to low corymbose or caespitose		
solitary		
clustered branchlets		
high corymbose or caespitose		
open arborescent		
foliacious		
plate		very high
Other categories		
soft corals		not known
sponges		not known
hydroids		not known
consolidated coral pavement		not damaged
unconsolidated dead coral {colonies or stands of coral skeletons not, or partially, cemented together by coralline algae}		broken up by trampling
sand		not damaged
rubble		sometimes reduced to smaller fragments

Figure 23 The coral shapes and substrate types that are commonly seen on coral reef flats.

transect line along each of these transects and record the identity of each coral shape or substrate type which lies directly under the line at each one metre interval. Figure 24 shows a filled out data sheet from a hypothetical survey.

The percentage cover of each category at the site can be estimated from this data as shown in Figure 24 and can be displayed as in Figure 25.

The survey can be modified by changing the number, length and position of the transects and the intervals between data collection points. The accuracy of percentage cover estimates will increase as the number of collection points increase. In some cases it may be appropriate to concentrate the survey on a particular area within a site which is particularly attractive or is likely to be very vulnerable to damage.

The survey can also be modified in another way where transect lines and tape measures are not used. In this situation the identity of each coral shape and substrate type adjacent to the centre of the surveyors walking boot is recorded as he or she walks along the imaginary transect line in the field. Care must be taken not to deliberately tread on certain features during the walk as it will bias the results.

Changes in community composition which are caused by trampling and which will be detected by this survey are most likely to take the following forms.

1. Decrease in the percentage cover of living coral.
2. Increase in the percentage cover of rubble.
3. Decrease in the percentage cover of unconsolidated substrate.
4. Greater decrease in the percentage cover of corals with high susceptibility to trampling damage compared to other corals.

Figure 24 (a) Data sheet from a hypothetical survey of coral composition and cover (b) Calculation of percentage cover.

TRANSECT	massive	encrusting	wedge blade	digitate	solitary	clustered branchlets	high corymbose caespitose	open arborescent	foliaceous	plate	sand	rubble	dead coral consolidated	dead coral unconsolidated
1	卌 /	/	/	//	/	////	/	//	/	/	卌 卌 //	/	////	卌 卌 //
2	//	//		/	///	卌 /		卌		/	卌 卌 卌		卌	卌 ///
3	///	卌	///		//	卌 ///	//	///	//		卌 /	///	//	卌 卌 ///
4	////	//	/	卌	//	///	/	卌	/	//	卌 ////	//	卌 ///	卌
5	卌 /	///		///		卌 ///		卌 //			卌 ///	/	卌 //	卌
6	///		/	卌 //	/	卌 /	/	卌 /	/	//	卌 卌 ///	///	////	卌 //
7	////	卌 /	//	///		////	/	////		/	卌 卌 /	卌	///	///
8	卌 卌	//		////	/	卌 ////		卌 /	/	/	卌 卌 卌 ///	/	卌 ///	/
9	卌 //	/	/	///	/	///	//	///	/		卌 //	//	卌 /	//
10	/	///	/	卌		卌 卌		卌 ///	/	/	卌 /	卌 卌 /	卌	/
TOTAL	46	25	10	33	11	61	8	49	8	9	105	29	52	57

(b) Total number of points scored = 503
Total number of points scored for massive corals = 46

therefore % cover massive corals $= \frac{46}{503} \times 100$
= 9.1%

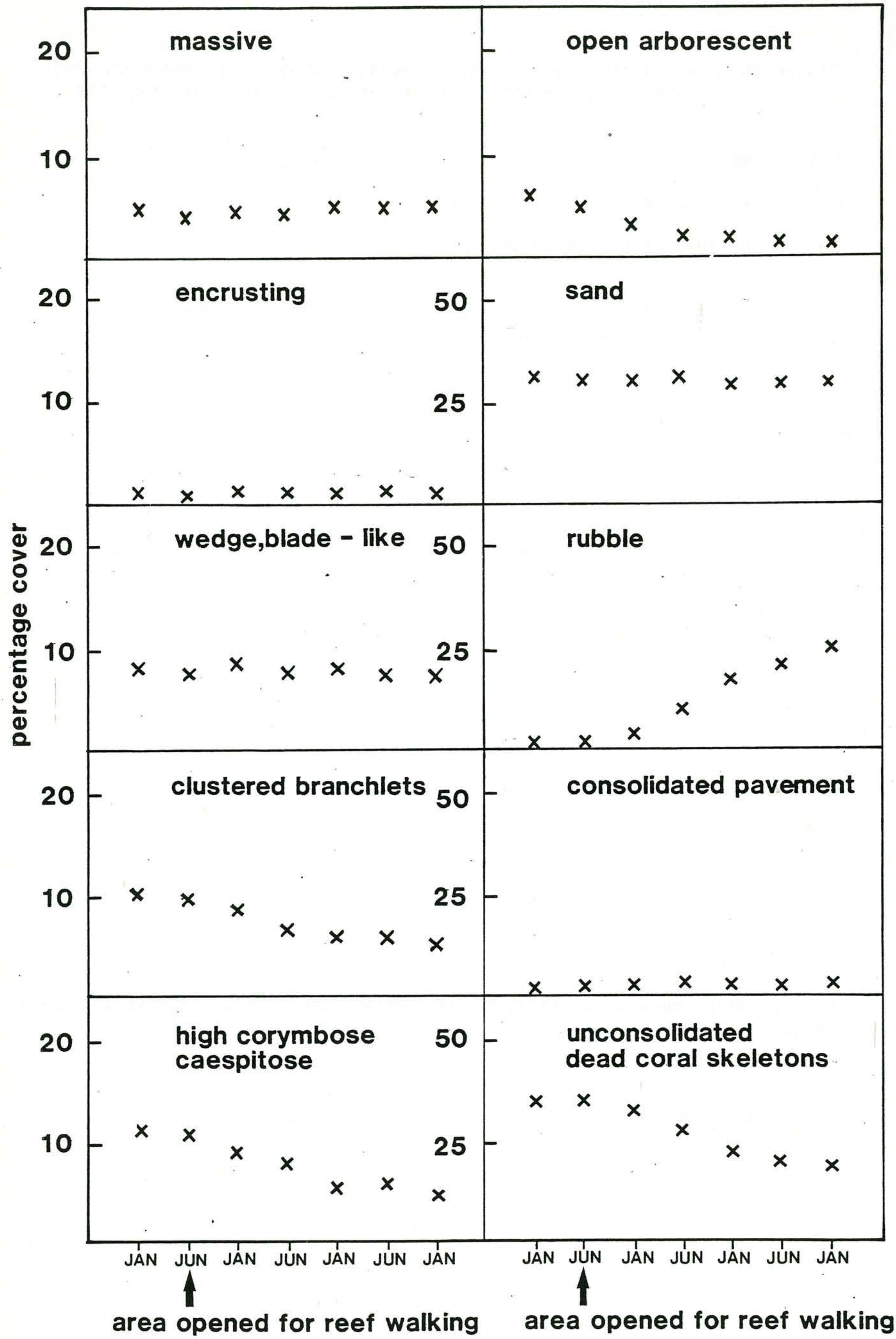


Figure 25 Results from a coral composition and cover monitoring scheme.

Figure 26 Reef walking questionnaire designed to collect some basic data on visitor movements and experiences at a reef walking site.

Date of walk:

Time of walk: Start: Finish:

Number and ages of people in group:

Draw the approximate path of your reef walk on the map provided

What did you enjoy about the walk?

What didn't you like about the walk?

Do you think there is anything the management could do to improve your reef walk?

Other comments?

8.4 Level of use

The level of use at a site can be most simply defined as the number of visitors per day. Counts of people can be made by tour guides, boat handlers or management personnel during low tide periods when the reef walking area is in use. The results can be expressed in terms of the average number of visitors per day for different months, seasons of years.

Very detailed studies looking at patterns within the reef walking site and visitor behaviour are beyond the scope of this manual. However, some general information of this sort can be obtained by asking visitors to fill out simple questionnaires (e.g. Figure 26) after their reef walks. The exact format of the questionnaire will depend on the information that the management wishes to collect.

8.5 Carrying capacity

The level of use at which management objectives cease to be met will be the maximum carrying capacity of a site. This can only be estimated if management objectives have been clearly set and if use levels and habitat changes are being monitored. The methods within this manual provide the basis for studies of this nature which will provide invaluable information for the future management of reef walking.

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